REFURBISHMENT OF THE BARBICAN CONCERT HALL – A TEN-YEAR HISTORY

C. Giegold and P. Calamia   Kirkegaard Associates, Chicago, Illinois, USA

1 INTRODUCTION

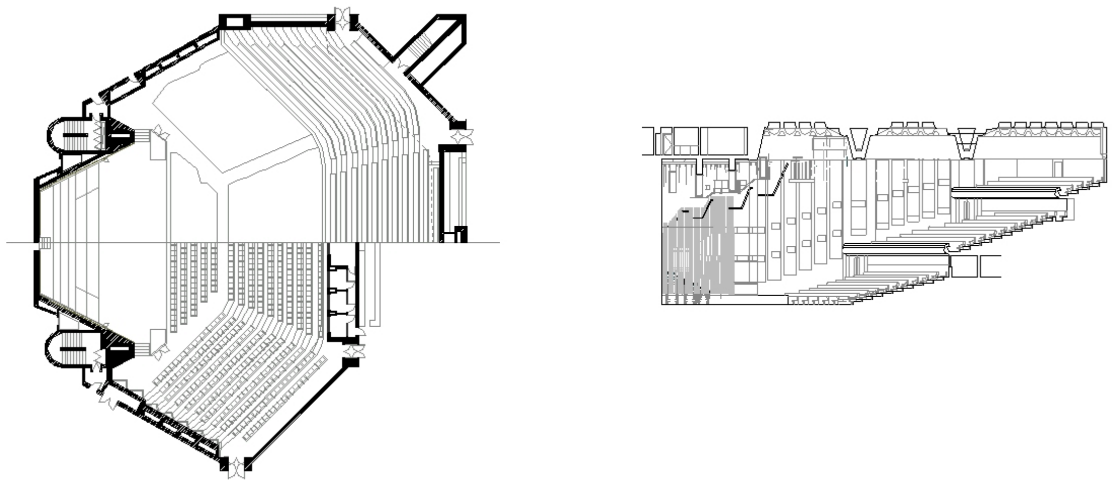
The Barbican Concert Hall is a thriving music venue, home to the London Symphony Orchestra and the BBC Symphony Orchestra. Aspects of its acoustics have been troublesome and disappointing from its opening in 1982, and there has long been a desire to address these issues. The hall's technical idiosyncrasies, themselves largely a function of its restricted volume and heroically scaled ceiling structure, have also been a source of concern, particularly as the facility's programming has blossomed in recent years to include a wide range of jazz, world music, and corporate events. Increasing demand on the space and increasing expectations on the part of performers and audiences have combined to induce a concerted effort to improve the room in many ways.

This paper will present and discuss the changes made to the concert hall in three distinct phases of renovation over the ten-year period of Kirkegaard Associates' involvement with the project. The most recent phase, that of the technical facilities upgrades completed in 2001 into which acoustics improvements were integrated, will be discussed in terms of the architectural/technical changes themselves, the design process that led to the final scope of the renovation, and quantification of the changes in measurable acoustic parameters.

2 ARCHITECTURAL AND TECHNICAL ASPECTS OF THE ORIGINAL ROOM

The concert hall was originally conceived as a conference facility with a seating capacity of about 2,000. The consequent emphasis on proximity to the stage led to a very wide, relatively shallow room configuration. By the time the space was reconceived as a concert hall, surrounding building areas had been developed to the extent that neither the reduction in width nor increase in height that would have made the space more inherently appropriate for music performance could be accommodated. During its first ten years, the hall gained a reputation for lack of musical clarity, poor ensemble conditions, poor balance and blend, inadequate reverberance, particularly at low frequencies, and very distant, unexciting listening in the Upper Circle.

The defining geometry of the room can be seen in plan (Figure 1a). Essentially octagonal in shape, the room has a maximum width of approximately 140 feet, with widely splayed side walls that direct little early energy to the center of the Stalls but instead are well-situated to generate significant echoes heard at the rear of the Stalls. The original, flat balcony fronts and rear wall of the Stalls were also found to be significant sources of echoes to the both the Platform and the Stalls. Early studies by Kirkegaard Associates using impulsive sound sources and both omnidirectional and directional microphones identified a series of such reflections deleterious to clarity.



(a) (b)

Figure 1: Existing hall, (a) Stalls and Circle-level plan, (b) longitudinal section.

Further, the considerable width of the room required a long roof span. With a structural vocabulary of concrete for the entire complex, post-tensioned concrete beams were the obvious choice for a 140 foot span. Two such beams span in each direction in the hall, dividing the ceiling into nine enormous coffers, and a waffle slab was developed to span between the beams. The effect of the ceiling structure was profound in acoustic terms: deep enough to walk through (deep enough, also, to serve as the primary distribution route for air supply to the hall) the beams obstructed access to broad areas of the ceiling plane and all but eliminated the ceiling as a useful reflective surface. What little energy from the platform that did make it to the ceiling encountered the deep concrete coffers of the waffle slab and was scattered. Wide areas of the center Stalls, the Circle and Upper Circle were thus left with neither significant side-wall reflections nor appropriate ceiling reflections. In this rather barren acoustic landscape, echoes from side walls, balcony fronts, and the control room facade were the defining features, leading to frequent use of the descriptors 'vague', 'veiled', and 'distant' in describing the hall's acoustic character.

Nevertheless, several aspects of the design were quite positive. Seating rakes are generous and provide excellent sightlines from most areas. Very few seats are beneath balcony overhangs and, hence, virtually all seats have excellent acoustic access to the ceiling and any potential reflective surfaces that might be developed there. With little in the way of useful reflections coming from the walls and no architecturally or financially viable means of introducing side-wall reflections, the ceiling would thus be critical to achieving substantial improvement in the hall's acoustic character.

In 1991, Kirkegaard Associates completed its acoustic master plan for the eventual renovation of the concert hall. Recommendations included echo control treatments to the side walls, balcony fronts, and rear-of-stalls wall, increasing the mass of the timber cladding to the walls of the audience chamber, addition of ceiling reflectors and a tunable ceiling over the platform, and, ultimately, a significant reorientation of seating areas to create a narrower room with more sidewall area to support lateral reflections to the stalls and to better support reverberation.

In 1994, the first significant phase of the renovation took place, addressing echo control and low-frequency response. This phase consisted of the installation of fabric covered absorption on the splayed side walls, quadratic-residue diffusers behind the Stalls audience, dramatic reshaping of the balcony fronts, and the stiffening of the serrated timber wall shaping with several layers of additional medium density fiberboard. While this series of changes led to a general improvement in clarity, somewhat improved ensemble conditions due to reduction of echoes, and perceivably improved bass response and warmth, this phase was mainly dedicated to eliminating undesirable phenomena as opposed to introducing new beneficial reflections.

For the next six years, as an increasingly demanding schedule of events continued to outstrip the capabilities of the space, and punctuated only by the permanent extension of the platform in 1996 to provide more area for the orchestra, the hall awaited the next phase of improvement. Impetus was finally provided by the deterioration of technical services in the hall. The Barbican came to realize that improvements to production lighting, house lighting, high-level access over the audience, and ventilation of the platform and audience chamber could be integrated with acoustic improvements at the ceiling.

3 PHASE 3 DESIGN PROCESS

Architects Caruso St John were commissioned in 2000 to lead the search for an integrated solution with a design team including theatre consultants Carr & Angier and acoustics consultants Kirkegaard Associates. Though the ceiling concept in Kirkegaard Associates' master plan suggested walkable ceiling reflectors over the audience, the initial architectural concept involved backlit translucent reflectors, which, by their nature, had to be relatively light in weight. Given the ample mass of the concrete enclosure of the room to support low-frequency reverberation, the lightweight ceiling concept seemed an approach worthy of study under the hypothesis that mid- and high-frequency ceiling reflections could be adequate to improve presence and intimacy as long as the reflectors themselves were not significantly absorptive at low frequencies.

A thin membrane of Ethyl Tetraflouro Ethylene (EFTE) was arrived at as the only material that met both aesthetic and fire requirements. This material is not inherently well damped, and resonant absorption was immediately identified as a potential problem. Acoustic testing was undertaken to evaluate both the reflectivity and the absorptive properties of the material when used as either a stretched membrane over a rigid frame or as an inflatable reflector potentially damped by the air within it. Since the material was neither readily available nor easily fabricated into the reflector sizes required for testing, KA fabricated its own mockups using .25mm polyethylene sheet. Reflectivity tests were conducted in KA's Chicago office. Absorption tests were conducted at Riverbank Acoustical Laboratories in Batavia, Illinois.

A 2.2m square frame was fabricated over which the polyethylene sheet was stretched in two directions, resulting in a very drum-like reflector that was tested both undamped and mass-loaded with steel mesh to investigate the effect of damping on the absorption characteristics.

Polyethylene sheet was fastened and sealed to each side of a second frame, with the polyethylene sized to provide the desired camber of the reflecting surface at the anticipated air pressure within the reflector. A pressure gauge and air valve were attached to the frame so that the pressure could be monitored at points during the testing processes. The inflatable reflector was tested for both reflectivity and absorption at several pressures ranging from 0.2 to 0.9 inches water gauge.

The stretched membrane behaved as expected given its readily apparent drum-like character. The undamped absorption tests showed negative absorption in the 80Hz third-octave band, indicating resonance in the membrane that outlasted the reverberation time of the room at that frequency. Mass-loading the membrane eliminated the ring but left significant resonant absorption at that frequency and disqualifying this reflector concept from further consideration.

Testing of the inflatable reflector indicated that reflectivity reasonably close to that of 12 mm plywood of similar surface area could be achieved at the pressures the ETFE material was intended to be used at and led us the opinion that reasonable reflections for clarity and ensemble could be expected of the approach. However, once again, significant low-frequency absorption was demonstrated in the reverberation chamber. (See Figure 2 below.) At the inflation pressures evaluated at Riverbank, there was no indication of ringing in the inflatable reflector, but it was clear from the test results that the higher pressures required for the desired reflectivity also brought considerably increased bass absorption.

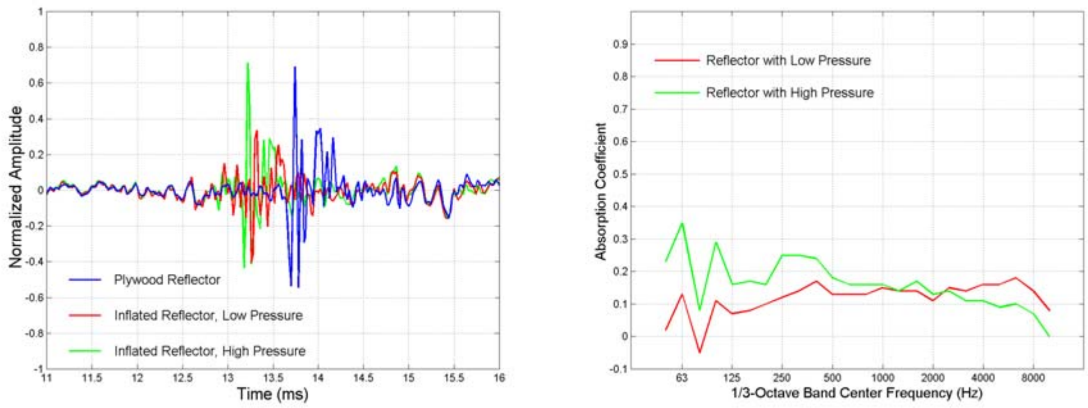


Figure 2: (a) Reflective and (b) absorptive behaviour of inflatable reflectors.

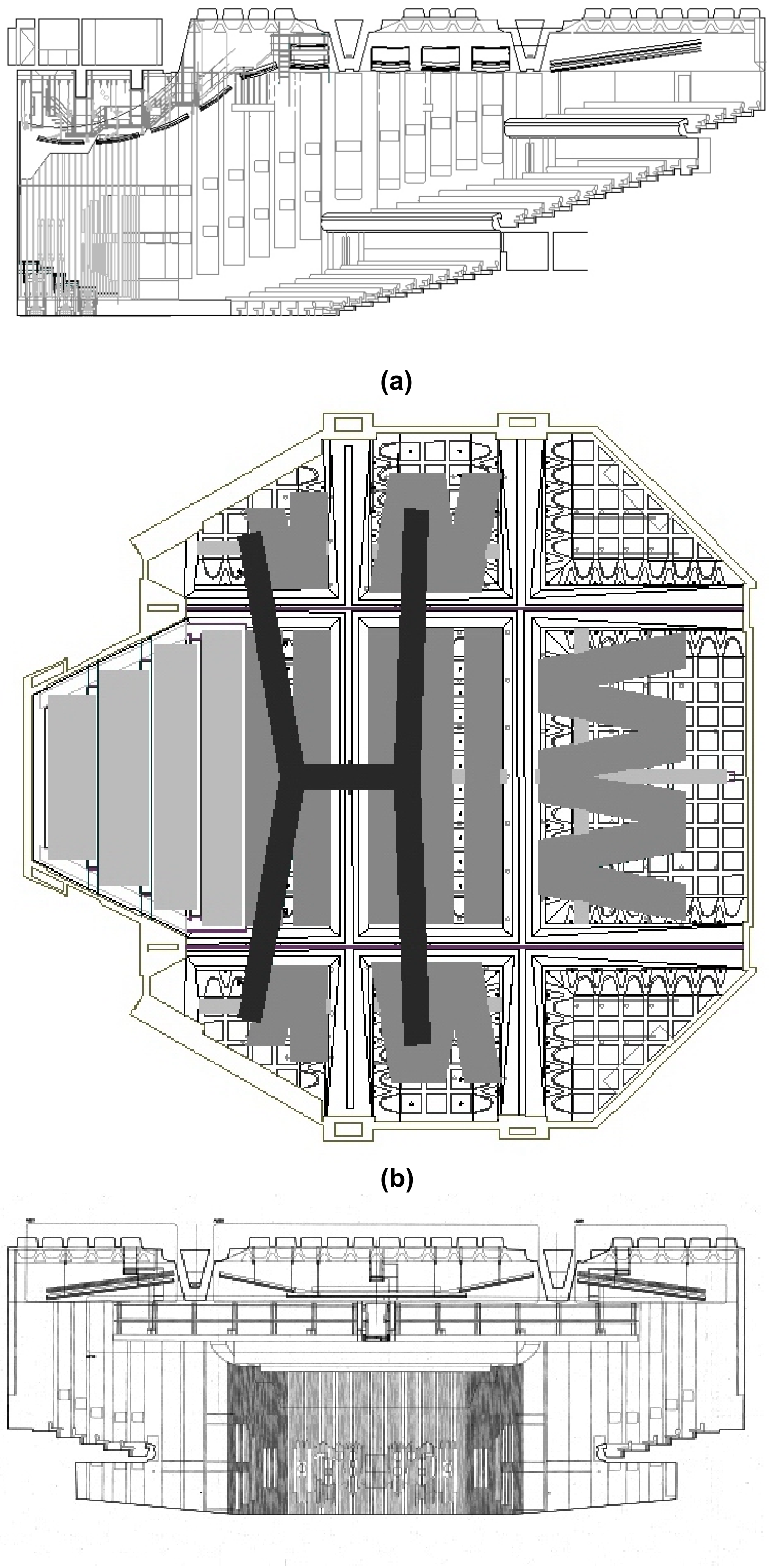
With a ticking clock and no obvious solution to this conundrum, along with the aesthetic non-viability of more inherently-damped fabrics such as canvas, the thin-reflector concept was deemed not valid for this project, and the decision was made to return to the heavy, walkable reflector system of the master plan for the final design.

4 DISCUSSION OF FINAL DESIGN

While the reflector composition analysis was underway, the configuration of the reflector system was in development as well. Along the lines of the recommendations in the master plan, the ceiling design was based on a series of four reflectors adjustable for height and tilt forming a canopy over the stage and a series of fixed reflectors approximately in plane with the soffits of the large concrete beams but oriented to work to advantage with specific surfaces of the beams and the side walls of the hall. The acoustic objective of the design was to provide a broad area of contiguous ceiling area to provide reflections with appropriate timing and frequency content to all areas of the room.

Figure 3 depicts the hall with the new canopy and reflectors in longitudinal and transverse section as well as in reflected ceiling plan. Openings between the reflectors provide sufficient access to the volume above the reflectors to avoid decoupling from the acoustic volume of the audience chamber. Reflectors are cambered at a radius of approximately 7m so that areas of coverage overlap at audience level. With few exceptions, all seating areas and the performance platform are covered by a minimum of two reflectors.

The fixed reflectors, which are up to approximately 10m in length and weigh approximately 100kg/m^2, are built up of 1.2m wide modules constructed of two layers 12mm medium density fiberboard laminated to each face of 200mm paper honeycomb for a total thickness of 250mm and finished on surfaces exposed to view with .8mm stainless steel sheet chemically treated to a burgundy/gold color. Steel trusses embedded within the thickness of the modules are joined by moment connections at each panel joint to stiffen the reflectors and allow suspension points to be spaced at considerably greater intervals than the 1.2mm module width. The reflector suspension rods, in turn, connect to steel grillage which fastens to the concrete ceiling structure utilizing the threaded inserts to which the temporary scaffold was attached during construction of the building in the 1980s. Fixed lighting bridges over the audience partially obstruct the ceiling reflectors and so were fitted with laminated MDF reflectors concealed behind perforated metal.



(a)

(b)

(c)

Figure 3: Drawings of the renovated hall: (a) longitudinal section, (b) reflected ceiling plan, (c) transverse section. Drawings from Caruso St John[2].

The transverse section indicates the relationship of the center-bay reflectors to the side surfaces of the concrete beams. The dihedral configuration of the reflectors was intended to develop a corner reflection that would increase the lateral energy arriving at listeners in the center zones of the Circle and Upper Circle and thereby narrow the room somewhat, in acoustic terms, for these listeners. Center seats in the Stalls do not have acoustic access to these surfaces.

The canopy reflectors are of similar construction, though the honeycomb thickness is reduced to 100mm for these reflectors to reduce their bulk. These reflectors range from 10 to 18.5 meters in width. They are adjustable for height and tilt and are thus capable of a wide range of potential canopy configurations. It is anticipated that three to four typical configurations will be developed during the tuning process. These configurations will be programmed into the control system to provide a manageable number of preset conditions.

As seen in Figure 4, a series of utility battens are stored above the canopy. Several of these battens can be deployed beneath the canopy while the canopy is set for orchestral use. This enables additional production lighting to be used for televised events, an important aspect of the BBC Symphony Orchestra's programming. Four flying access bridges located in the gaps between each pair of reflectors and immediately upstage of the upstage reflector allow production lighting to be focused from its deployed position. The reflectors genuflect to allow the flying bridges to pass by them while the bridges are in motion. Concert lighting is mounted to the underside of each bridge.

High-level catwalks at the side walls of the platform provide access to the flying bridges and are clad with MDF panels to reduce the gaps at the ends of the four reflectors and add corner reflections to the series of reflections generated by the canopy. Small areas of occupiable space above the platform were taken over as hoist rooms for the reflector and access bridge rigging equipment.

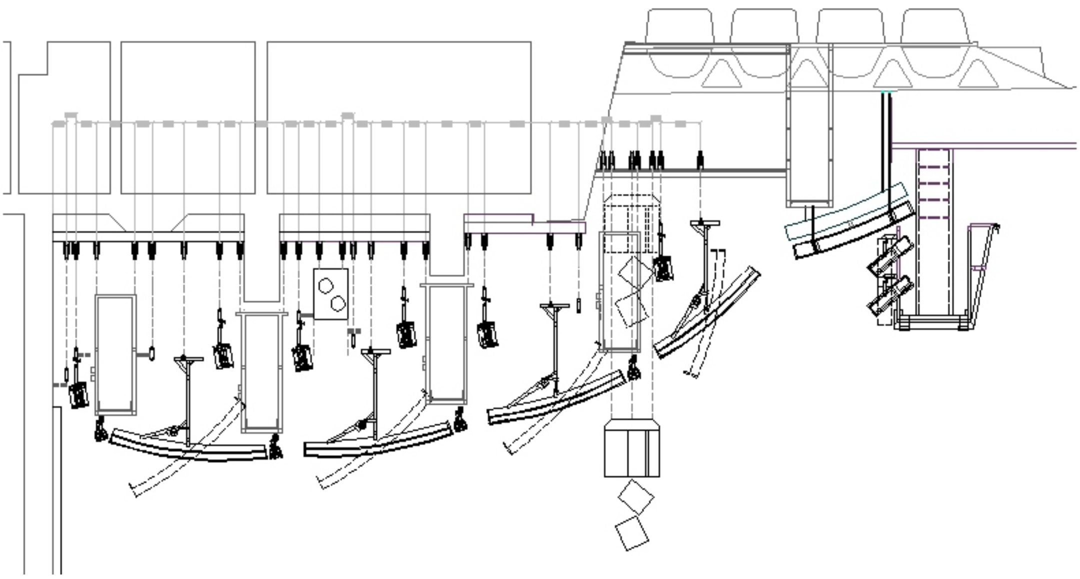


Figure 4: Detail of canopy showing reflectors, flying access bridges, utility battens, projection screen, and loudspeaker cluster. The first fixed reflector and light bridge can be seen at the right side of the figure. Detail from Carr & Angier[3].

As part of the renovation, new air handling equipment was installed for both the house and platform systems, and the flow of air was reversed in the house so that air is now delivered from beneath the seats and extracted at high level. In the original system, voids in the concrete beams served as ducts and distributed supply air to drop tubes that hung down approximately 3 meters from the waffle slab. In the renovation, the drop tubes were removed leaving the apertures in the waffle slab to serve as distributed extract openings. All modifications to ductwork required for the flow reversal were accomplished in the plant room beneath the concert hall. The modifications to the system have reduced background noise as indicated in Figure 5. A regenerated noise condition in the underfloor plenum affects the center and rear of the Center Stalls, but revisions to the plenum in question are planned to eliminate this residual noise.

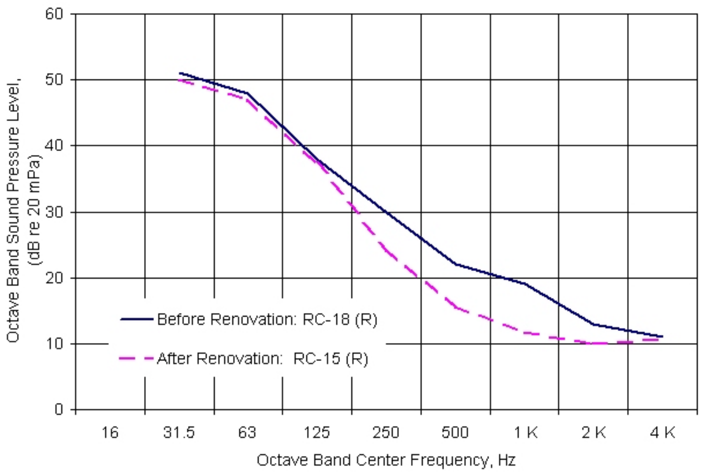
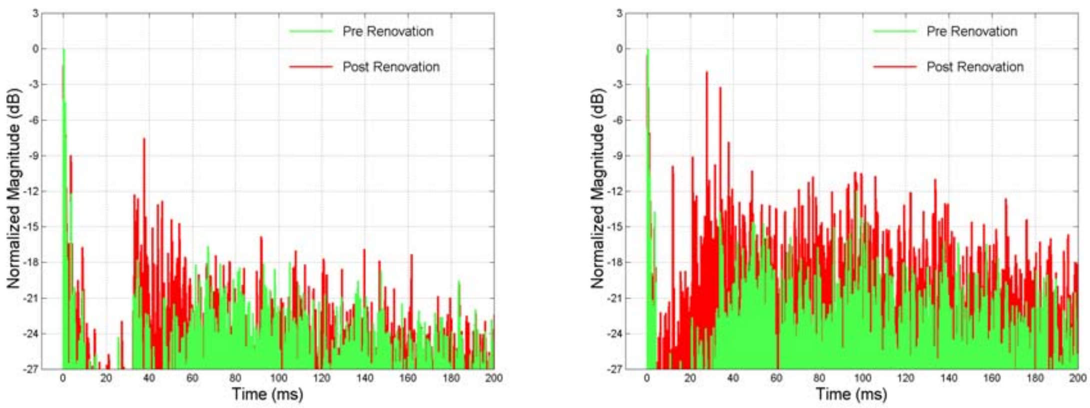


Figure 5: Background noise levels measured in the Upper Circle before and after the 2001 renovation.

5 DOCUMENTATION OF RESULTS

Acoustic measurements were taken from a variety of source positions on the platform to a variety of receiver positions both on the platform and in the audience chamber. A subset of these measurements is shown in Figures 6 and 7 below. The most striking feature in Figure 6 is the measured increase in early energy (within 80 ms of the arrival of the direct sound) at all levels of the audience chamber.



(a) **(b)**

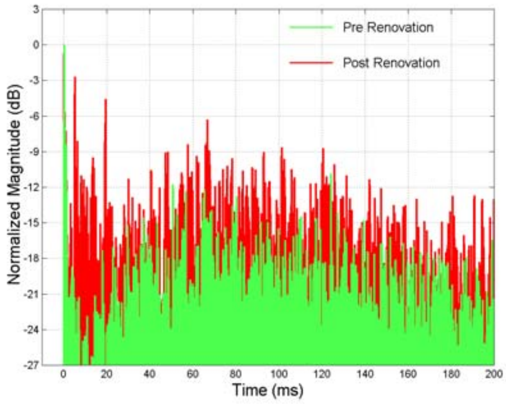


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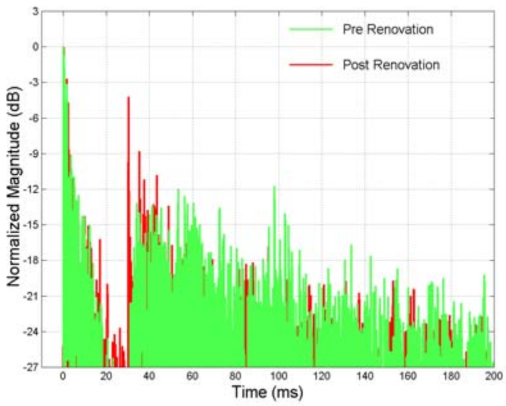
Figure 6: Impulse responses measured at (a) Stalls Row L Seat 35, (b) Circle Row D Seat 46, (c) Upper Circle Row B Seat 44 prior to and just after the 2001 renovation.



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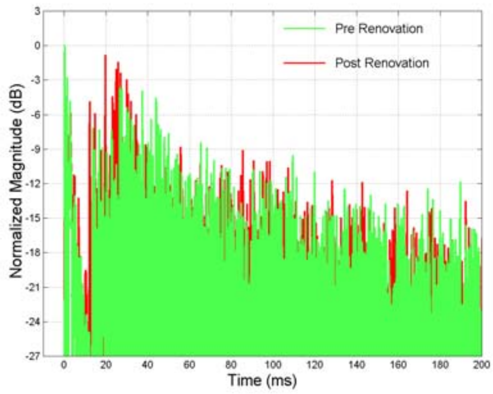
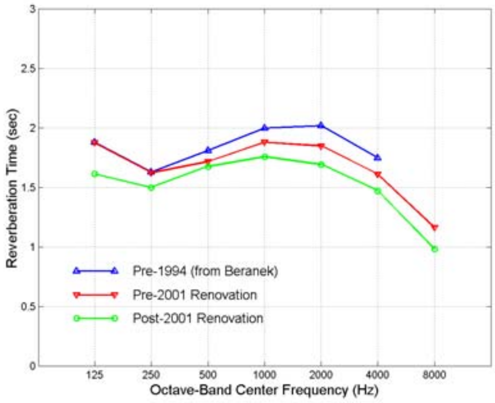


(b)

Figure 7: Impulse response measured with source at Leader's position and receivers at (a) oboe and (b) brass positions.

Standard acoustical parameters were also extracted from the measured impulse responses, a subset of which are shown in Figure 8 below. It is particularly interesting to note the decrease in reverberation time (Figure 8 (a)) which is likely due to the increased redirection of upward-bound sound toward the absorptive audience plane by the new canopy and reflectors, and the small reduction in volume due to the effective lowering of the ceiling. Inadequate reverberation has long been considered one of the hall's major shortcomings, but the measured decreases due to the renovations have not been the subject of further complaints. This is quite likely due to the more noticeable increases in strength and clarity, as well as to the reduced background noise in the hall which allows the late portion of the reverberation to remain audible.



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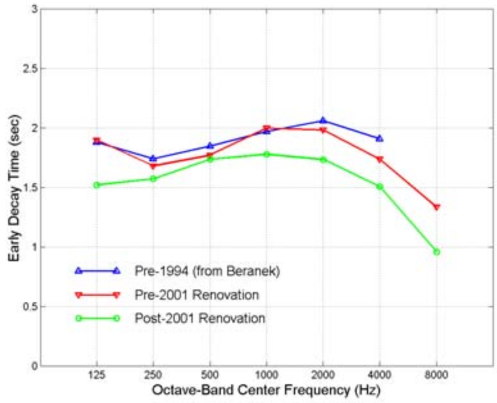

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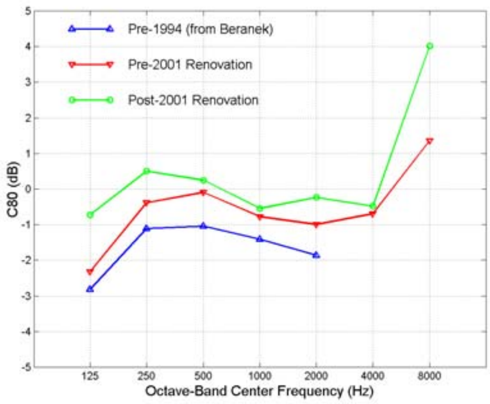

(c)

Figure 8: Average unoccupied data from the hall: a) reverberation time, (b) early decay time, (c) C80. Pre-1994 data from Beranek[1].

6 CONCLUSIONS

The renovation of the Barbican Concert Hall has been greeted with considerable enthusiasm from both musicians and audiences. Loudness, clarity, presence, balance, and blend all seem to be positively affected, and visual inspection of the impulse response graphs bears this out. It is interesting that, as described above, the C80 parameter does not communicate the extent of improvement in musical clarity that one experiences in the hall. Further, the perception of many who have commented on the changes is that the hall has greater warmth than before, even though low-frequency reverberation and bass ratio have actually diminished.

7 REFERENCES

1. L. Beranek, Concert and Opera Halls: How They Sound, Acoustical Society of America, 608-609. (1996).
2. Barbican Concert Hall design and construction documents, Caruso St John Architects. (2001).
3. Barbican Concert Hall design documents from Carr & Angier Theatre Consultants. (2001).